METHOD AND APPARATUS FOR OPTIMIZING QUANTIZER VALUES IN AN IMAGE ENCODER

BACKGROUND OF THE INVENTION

The invention relates to computing quantization values used for encoding coeffients of a digital image or video frame and more particularly to optimizing the computed quantization values to reduce distortion in the digital image or video frame when encoding is performed with a limited number of bits.

In many of today's image and video coders, the quality of encoded images is controlled by selecting one or more quality parameters. Block-based image and video coders, use a parameter known as a quantization scale or step for each block of pixels in the image. The quantization steps are used for scaling pixel values within the same step ranges to the same values. Image blocks encoded with the same quantization scale have approximately the same quality. The number of bits needed for encoding an image depends on desired image quality (quantization scales) and on the inherent statistics of the image. As a result, different images encoded with the same scales (same image quality) will occupy a different number of bits.

In many applications, the number of bits available for encoding one or several frames is fixed in advance, and some technique is necessary to select the quantization scales that will produce that target number of bits and encode the video frames with the highest possible quality. For example, in a digital video recording, a group of frames (GOP) must occupy the same number of bits for an efficient fast-forward/fast-rewind capability. In video telephony, the channel rate, communication delay, and size of encoder buffers determine the available number of bits for one or more frames.

Existing quantizer or buffer control methods are classified into three major types. A first type of quantizer control method encodes each image block several times with a set of quantization scales. The number of bits produced for each case is measured and a scale for each block is smartly selected so the sum of the bits for all combined blocks hits the desired target bit number. The first type of

quantizer control techniques cannot be used for real-time encoding because of the high computational complexity required to encode each image block multiple times.

The first type of quantizer control is described in the following publications: K. Ramchandran, A. Ortega, and M. Vetterli, "Bit Allocation for Dependent Quantization with Applications to Multi-Resolution and MPEG Video Coders," IEEE Trans. on Image Processing, Vol. 3, N. 5, pp. 533-545, September 1994; W. Ding and B. Liu, "Rate Control of MPEG Video Coding and Recording by Rate-Quantization Modeling," IEEE Trans. on Circuits and Systems for Video Technology, Vol. 6, N. 1, pp. 12-19, February 1996; and L.J. Lin, A. Ortega, and C.C. J. Kuo, "Rate Control Using Spline-Interpolated R-D Characteristics," Proc. of SPIE Visual Communications and Image Processing, pp. 111-122, Orlando, FL, March 1996.

A second type of quantizer control technique measures the number of bits spent in previously encoded image blocks and measures other parameters such as, buffer fullness, block activity, etc. These measurements are used to select the quantization scale for the current block. The second type of quantizer control is popular for real-time encoding because of its low computational complexity. However, the second type of quantizer control is inaccurate in achieving the target number of bits and must be combined with additional encoding techniques to avoid bit or buffer overflow and underflow.

The second method is described in the following publications: U.S. Patent No. 5,038,209 entitled "Adaptive Buffer/Quantizer Control for Transform Video Coders", issued August 6, 1991 to H.M. Ming; U.S. Patent No. 5,159,447 entitled "Buffer Control for Variable Bit-Rate Channel", issued October 27, 1992 to B.G. Haskell and A.R. Reibman; and U.S. Patent No. 5,141,383 entitled "Pseudo-Constant Bit Rate Video Coding with Quantization Parameter Adjustment", issued August 31, 1993 to C.T. Cheng and A.H. Wong.

A third type of quantizer control technique uses a model to predict the number of bits needed for encoding the image blocks. The quantizer model

includes the blocks' quantization scales and other parameters, such as, block variances. The quantization scales are determined by some mathematical optimization of the encoder model. The third type of quantizer control is computationally simple and can be used in real-time, but is highly sensitive to model errors and often produces inaccurate results.

The third type of quantizer control technique is described in the following publications. E.D. Frimout, J. Biemond, and R.L. Lagendik, "Forward Rate Control for MPEG Recording," Proc. of SPIE Visual Communications and Image Processing, Cambridge, MA, pp. 184-194, November 1993; U.S. Patent No. 5,323,187 entitled, "Image Compression System by Setting Fixed Bit Rates", issued June 21, 1994 to K. Park and A. Nicoulin, "Composite Source Modeling for Image Compression," Ph.D. Thesis N. 1444 (1995), Ecole Polytechnique Federale de Lausanne, Chapter 6,1995.

Thus, a need remains for improving the image quality of quantized image or video frames while reducing the time and computational complexity required to generate optimized quantization values.

SUMMARY OF THE INVENTION

A quantizer controller generates quantization values using a new block-adaptive, Lagrangian optimization. The quantizer controller is updated and improved using information from earlier quantized blocks. The quantizer controller is robust to model errors and produces results as accurate as type-1 quantizer control techniques, while having the simpler computational complexity of the type-2 quantizer control techniques.

The quantizer controller identifies a target bit value equal to a total number of bits available for encoding the frame. A total amount of distortion in the frame is modeled according to the predicted quantization values assigned to each one of the blocks. The predicted quantization values are characterized according to an amount of energy in each block and a number of bits available for encoding each block. Optimum quantization values are adapted to each block by minimizing the modeled distortion in the frame subject to the constraint that the total number of bits for

encoding the frame is equal to the target bit value. Each block is then encoded with the optimized quantization value.

The quantizer controller is adaptive to each block by reducing quantization values for the blocks having less energy and increasing the quantization values for the blocks having more energy. The quantization values assigned to the blocks are also optimized according to a number of image blocks remaining to be encoded and a number of bits still available for encoding the remaining image blocks.

Different weighting factors are optionally applied to the quantization values that vary the accuracy of the encoded blocks. One weighting factor is applied to the quantization values according to the location of the block in the frame. Optimized quantization values are applied to blocks in each frame, frames in a group of multiple frames or applied generally for any region in an array of image data.

The quantizer controller only encodes the image once to accurately generate the quantization values for each block. The quantization values produce a target number of bits for the encoded image or video frame. Thus, the quantizer controller is less computationally exhaustive than a quantizer control technique of similar accuracy.

The general framework of the quantizer controller can be used in a variety of quantizer/rate control strategies. For example, the quantizer controller can be used to select in real-time the value of the quantization scales for the Discrete Cosine Transform DCT-based encoding of the frame macroblocks in the current video coding standards MPEG 1-2 and 4, H.261, H.263, and H.263+. A frame, several frames, or several macroblocks within a frame are encoded with a fixed number of bits.

The foregoing and other objects, features and advantages of the invention will become more readily apparent from the following detailed description of a preferred embodiment of the invention, which proceeds with reference to the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a schematic diagram of multiple image frames each including multiple blocks assigned optimized quantization values according to the invention.

FIG. 2 is a block diagram of an image coder according to one embodiment of the invention.

FIG. 3 is a step diagram for generating the optimized quantization values.

FIGS. 4 and 5 show results from applying the optimized quantization values to image data.

FIG. 6 is a block diagram of the quantizer controller according to one embodiment of the invention.

DETAILED DESCRIPTION

A block-based image coder 12 is used to describe the invention. However, the invention can be used for controlling the quantizer of any image or video coder.

Referring to FIG. 1, in block-based image coding, images 15 are transmitted in multiple frames 26. Each frame 26 is decomposed into multiple image blocks 14 of the same size, typically of 16x16 pixels per block. The number of bits B_i produced after encoding an ith image block 14, is a function of the value of a quantization parameter Q_i and the statistics of the block. For example, image block i = 9 contains more image information (energy) σ_i than image block i = 17. This is because the image in block i = 9 contains portions of a facial image along with background information. Conversely, image block i = 17 has less image information energy σ_i because it contains substantially the same background imagery in substantially each pixel location.

Referring to FIG. 2, the pixel values for each image block 14 are transformed into a set of coefficients, for example using a Discrete Cosine Transform (DCT) in block transform 16. These coefficients are quantized in block quantization 18 and encoded in coder 20. Bits B_i of the encoded and quantized image blocks 14 are then transmitted over a communication channel 21 over a telephone line, microwave channel, etc. to a receiver (not shown). The receiver

includes a decoder that decodes the quantized bits and an inverse transform block that performs an Inverse Discrete Cosine Transform (IDCT). The decoded bits B_i are then displayed on a visual display screen to a user.

Quantization of the transformed coefficients in quantization block 18 is a key procedure since it determines the quality with which the image block 14 will be encoded. The quantization of the ith block 14 is controlled by the parameter, Q_i. In the H.261 and H.263 video coding standards, Q_i is known as the quantization step for the ith block and its value corresponds to half the step size used for quantizing the transformed coefficients. In the MPEG-1 and MPEG-2 standards, Q_i is called the quantization scale and the jth coefficient of a block is quantized using a quantizer of step size $Q_i w_j$, where w_j is the jth value of a quantization matrix chosen by the designer of the MPEG codec.

Let N be the number of 16x16 image blocks in one image frame 26. The total number of bits B available for encoding one image frame 26 is:

$$B = B_1 + B_2 + B_3 + \ldots + B_N, \qquad (1)$$

where the value of B depends on the quantization parameters selected, $Q_1, Q_2, \ldots, Q_N$, and the statistics of the blocks. The invention comprises a quantizer controller 22 (FIG. 1) that chooses optimum values for the Q_i's for a limited total number of available bits B for encoding the frames 26. The quantizer controller 22 is implemented in a variety of different maps including in software in a programmable processing unit with dedicated hardware.

In image coding, the image blocks 14 are said to be intracoded or of class *intra*. In video coding, many of the blocks 14 in a frame 26 are very similar to blocks in previous frames. The values of the pixels in a block 14 are often predicted from previously encoded blocks and only the difference or prediction error is encoded. These blocks are said to be intercoded or of class *inter*. The invention can be used in frames with both *intra* and *inter* blocks.

Encoder Model

The following model in equation 2 identifies the number of bits invested in the ith image block :

$$B_i = A\left(K\frac{\sigma_i^2}{Q_i^2} + C \right), \qquad (2)$$

The value Q_i is the quantizer step size or quantization scale, A is the number of pixels in a block (e.g., in MPEG and H.263 $A = 16^2$ pixels), K and C are constants, and σ_i is the empirical standard deviation of the pixels in the block,

$$\sigma_i = \sqrt{\frac{1}{A}\sum_{j=1}^{A}(P_i(j) - \overline{P}_i)^2} \ . \qquad (3)$$

The value $P_i(j)$ is the jth pixel in the ith block and $\overline{P}_i$ is the average of the pixel values in the block where,

$$\overline{P}_i = \frac{1}{A}\sum_{j=1}^{A}P_i(j) \, . \qquad (4)$$

For color images, the $P_i(j)$'s are the values of the luminance and chrominance components of the respective pixels. The model in equation 2 is derived using a rate-distortion analysis of the block's encoder. The value of K in equation 2 depends on the statistics of the image blocks 26 and the quantization matrix used in the encoder. For example, it can be shown that if the pixel values are approximately uncorrelated and Gaussian distributed, and the quantization matrix is flat with unitary weights (i.e., $w_j = 1$ for all j), then $K=\pi/\ln 2$. The constant C in equation 2 models the average number of bits per pixel used for encoding the coder's overhead. For example, C accounts for header and syntax information, pixel color or chrominance components, transmitted Q values, motion vectors, etc. sent to the receiver for decoding the image blocks. If the values of K and C are not known, they are estimated with an inventive technique

described below in the section entitled, "Updating the Parameters of the Encoder Model".

Equation 5 models distortion D for the N encoded blocks,

$$D = \frac{1}{N}\sum_{i=1}^{N} \alpha_i^2 \frac{Q_i^2}{12}, \tag{5}$$

where the α_i's are weights chosen to incorporate the importance or cost of the block distortion. For example, larger α_i's are chosen for image blocks having artifacts more visible to the human eye or for image blocks that belong to more important objects in the scene. If $\alpha_1 = \alpha_2 = \ldots = \alpha_N = 1$, the distortion represented by equation 5 is approximately the mean squared error (MSE) between the original and encoded blocks.

Optimization

The quantizer controller 22 (FIG. 1) selects the optimal quantization values, $Q^*_1, Q^*_2, \ldots, Q^*_N$, that minimize the distortion model in equation 5, subject to the constraint that the total number of bits must be equal to B as defined in equation 1, which can be expressed mathematically as follows:

$$Q_1^*, \ldots, Q_N^* = \underset{\substack{Q_1, \ldots, Q_N: \\ \sum_{j=1}^{N} B_j = B}}{\arg\min} \ \frac{1}{N}\sum_{j=1}^{N} \alpha_j^2 \frac{Q_j^2}{12} \tag{6a}$$

The next objective is to find a formula for each of the Q_i^*'s. To do this, the method of Lagrange is used to convert the constrained-minimization in equation (6a) to the following:

$$Q_1^*, \ldots, Q_N^* = \underset{Q_1, \ldots, Q_N}{\arg\min} \ \frac{1}{N}\sum_{i=1}^{N} \alpha_j^2 \frac{Q_j^2}{12} + \lambda\left(\sum_{j=1}^{N} B_j - B\right), \tag{6b}$$

where λ is called the Lagrange multiplier. Next, equation (2) is used for B_j in (6b) to obtain:

$$Q_1^*,\ldots,Q_N^* = \arg\min_{Q_1,\ldots,Q_N} \frac{1}{N}\sum_{j=1}^{N}\alpha_j^2\frac{Q_j^2}{12}+\lambda\sum_{j=1}^{N}A\left(K\frac{\sigma_j^2}{Q_j^2}+C\right)-\lambda B \qquad (6c)$$

Finally, by setting partial derivatives in (6c) to zero, the following formula is derived for the optimal quantizer step size for the i-th image block:

$$Q_i^* = \sqrt{\frac{AK}{(B-ANC)}\frac{\sigma_i}{\alpha_i}\sum_{k=1}^{N}\alpha_k\sigma_k} . \qquad (6)$$

Moreover, if i-1 blocks 26 have already been quantized and encoded, the optimal quantization parameter for the ith block is,

$$Q_i^* = \sqrt{\frac{AK}{(\tilde{B}_i-AN_iC)}\frac{\sigma_i}{\alpha_i}\sum_{k=i}^{N}\alpha_k\sigma_k} , \qquad (7)$$

where $N_i = N-i+1$ is the number of image blocks that remain to be encoded and $\tilde{B}_i$ is the number of bits available to encode them,

$$\tilde{B}_i = B-\sum_{j=1}^{i-1}B_j = \tilde{B}_{i-1}-B_{i-1} = \tilde{B}_{i-1}-A\left(K\frac{\sigma_{i-1}^2}{Q_{i-1}^{*2}}+C\right), \qquad (8)$$

where B_{i-1} is obtained using equation 2 with the optimized quantization value Q_{i-1}^*. Thus, equations 6 and 7 generate optimized quantization values that minimize distortion for a limited number of available bits. As a result, using the same number of bits, the image in frame 26 in FIG. 1 will have less distortion than other quantization schemes when displayed on a display unit at the receiver end of the channel 21.

QUANTIZER CONTROL METHOD

FIG. 3 describes the steps performed by quantizer controller 22 (FIG. 2) for selecting quantizer values used for encoding N image blocks 14 with B bits. Note that N could be the number of blocks in an image, part of an image, several images, or generally any region of an image.

Step 1. Receive energy values and initialization.

Pixel values for the N image blocks are obtained to the quantizer controller 22 from the digital image (FIG. 2) in step 1A. Initialization is performed in step 1B by setting $i = 1$ (first block), $\tilde{B}_1 = B$ (available bits), $N_1 = N$ (number of blocks). Let $S_1 = \sum_{k=1}^{N} \alpha_k \sigma_k$, where the σ_k's are found using equation 3 and the α_k's are preset (e.g., set $\alpha_1 = \alpha_2 = \ldots = \alpha_N = 1$ to minimize mean squared error). In one example, the amount of energy σ_i is derived from the DCT coefficients of the pixel values generated by transform block 16.

For a fixed mode, the values of the parameters K and C in the encoder model in equation 7 are known or estimated in advance. For example, using linear regression, $K_1 = K$ and $C_1 = C$. For an adaptive mode, the model parameters are not known, K_1 and C_1 are then set to some small non-negative values. For example, experiments have shown $K_1 = 0.5$ and $C_1 = 0$ to be good initial estimates. In video coding, K_1 and C_1 can be set to the values K_{N+1} and C_{N+1}, respectively, from the previous encoded frame.

Step 2. Compute the optimal quantization parameter for the ith block.

If the values of the Q-parameters are restricted to a fixed set (e.g., in H.263, QP=Q_i/2 and takes values 1,2,3,..., 31,), Q_i* is rounded to the nearest value in the set. The square root operation is then implemented using look-up tables, where

$$Q_i^* = \sqrt{\frac{A K_i}{\left(\tilde{B}_i - A N_i C_i\right)} \frac{\sigma_i}{\alpha_i} S_i}$$

Step 3. Encode the ith block with a block-based coder.

B_i' is the number of bits used to encode the ith block, compute

$$\tilde{B}_{i+1} = \tilde{B}_i - B_i', \quad S_{i+1} = S_i - \alpha_i \sigma_i, \quad \text{and } N_{i+1} = N_i - 1.$$

Step 4. Update quantizer values.

In step 4, the parameters K_{i+1} and C_{i+1} are updated in the quantizer controller 22. For the fixed mode, $K_{i+1} = K$, $C_{i+1} = C$. For the adaptive mode, the updates K_{i+1} and C_{i+1} are found using a model fitting technique. One example of a model fitting technique is described below in the section entitled "Updating Parameters in the Quantizer controller".

Step 5. Generate quantizer value for next block.

If i = N in decision step 5, quantization values have been derived for all image blocks 14 and the quantizer controller 22 stops. If all of the image blocks 14 have not been quantized, the quantizer controller 22 receives the coefficients for the next image block i = i+1 in step 6, and jumps back to step 2. The quantization value for block i = i+1 are then derived as described above.

Referring to FIGS. 4 and 5, the frames of video sequences encoded by quantizer controller 22 where compared to those of a Telenor H.263 offline method, which is the quantizer control technique adopted for MPEG-4 anchors.

In FIG. 4, the total number of bits per video frame obtained by the quantization technique described in FIG. 3 are shown in solid line. The H.263 offline encoding technique is shown in dashed line. Encoding was performed on 133 frames of a well-known video sequence "Foreman". The target number of bits B is 11200 bits per frame. FIG. 5 is like FIG. 4, but for 140 frames of the video sequence "Mother and Daughter" with B=6400.

The quantizer controller 22 produces a significantly more accurate and steady number of bits per frame. Similar results were obtained for a wide range of bit rates. In the experiments, there were little if no visible differences in the quality of the two encoded video sequences. The signal to noise ratio performance

of the images processed by quantizer controller 22 was only 0.1-0.3 dB lower on average. Thus, even though the image is only encoded once, quantizer controller 22 achieves the target bit rate accurately with high image quality at every frame.

Alternative Implementations

Several quantization variations are based on the base quantization optimization framework discussed above. If the computation of all σ_k's in Step 1B of FIG. 3 cannot be performed in advance, a good estimate for S_1 is used, such as the value of S_1 from the previous video frame 26.

A low-complexity estimate of S_1 can be used, in order to further reduce computational complexity. For the low complexity estimate, equation 3 is replaced by equation 9,

$$\sigma_i = \frac{1}{A}\sum_{j=1}^{A} abs(P_i(j) - \overline{P}_i), \qquad (9)$$

where *abs(x)* is the absolute value of *x*. In video coding, the mean value of pixels in *inter* blocks is usually zero and hence equation 9 may be simplified by setting $\overline{P}_i = 0$.

A fixed optimization selects the quantization parameters using equation 6 instead of equation 7. To do this, in step 3 in FIG. 3, the values for $\tilde{B}_{i+1}$, S_{i+1}, and N_{i+1} are replaced by $\tilde{B}_{i+1} = B$, $S_{i+1} = S_1$, and $N_{i+1} = N$, respectively.

For a variable-rate channel, if the number of bits available after encoding i blocks changes to $\hat{B}$, because of a change of channel rate or other factors, set $\tilde{B}_{i+1} = \hat{B}$ in step 3.

The quantization model defined in equation 2 can be generalized to equation 10,

$$B_j = A_j\left(K\frac{\sigma_j^{\phi}}{Q_j^{\gamma}} + C\right), \qquad (10)$$

where A_j is the number of pixels in the jth region. The region of quantization does not need to be a block. Additional model parameters ϕ and γ can either be set prior to quantization or obtained using parameter estimation techniques described below. If the quantization model in equation 10 is used in step 2, the optimized quantization values Q_i^*'s are derived using equation 11,

$$Q_i^* = \left(\frac{K A_i^{\frac{\gamma}{\gamma+2}}}{\tilde{B}_i - C\sum_{n=i}^{N} A_n} \frac{\sigma_i^{\phi\frac{\gamma}{\gamma+2}}}{\alpha_i^{2\frac{\gamma}{\gamma+2}}} S_i \right)^{\frac{1}{\gamma}}, \tag{11}$$

in step 1, S_1 is replaced by $S_1 = \sum_{n=1}^{N} (A_n \sigma_n^{\phi})^{\frac{2}{\gamma+2}} \alpha_n^{\frac{2\gamma}{\gamma+2}}$. In step 3, S_{i+1} is replaced by $S_{i+1} = S_i - (A_i \sigma_i^{\phi})^{\frac{2}{\gamma+2}} \alpha_i^{\frac{2\gamma}{\gamma+2}}$.

Encoding Intra and Inter Blocks.

If some of the blocks to be encoded are of class *intra* (in the same frame) and some *inter* (between different frames), performance of the quantizer controller 22 can be improved by dividing the standard deviation of the *intra* blocks by a factor $\sqrt{\beta}$. Specifically, after computing the value for the σ_k's in step 1, the factor $\sqrt{\beta}$ is applied as follows:

$$\sigma_k = \begin{cases} \dfrac{\sigma_k}{\sqrt{\beta}} & \text{if kth block is intra} \\ \sigma_k & \text{otherwise} \end{cases}.$$

The factor β is,

$$\beta = \frac{K_P}{K_I}.$$

The values K_I and K_P are the averages of the K's measured for the *intra* and *inter* blocks, respectively. The value of β is estimated and updated during encoding. During experimentation it was found that using a constant $\beta = 3$ works well.

Frame-Based Quantizer Control.

If the quantization step is fixed for all the blocks 14 within a frame 26, the same quantizer controller 22 shown in FIG.1 can be used for encoding one or several frames. The parameters are reinterpreted so that: N = Number of frames, B = Bits available for encoding the N frames, i = Frame number in the video sequence, Q_i = Quantization step for all the blocks in the ith frame, and A = Number of pixels in a frame.

The parameters α_i, σ_i, B'_i, are the weight, variance, and bits for the ith frame, respectively. The parameters K_i and C_i are updates of the coder model for that frame.

If computational complexity is not an issue, each image block 14 can be encoded several times and, using a classical model fitting procedure (e.g., least-squares fit, linear regression, etc.), a good estimate of the K_i's and C_i's for the blocks can be found in advance. Then, in step 2, the quantization values Q_i^* are determined according to,

$$Q_i^* = \sqrt{\frac{A\sqrt{K_i}}{\left(\tilde{B}_i - A\sum_{i=1}^{N} C_i\right)} \frac{\sigma_i}{\alpha_i} S_i} \; .$$

In Step 1, S_1 is replaced by $S_1 = \sum_{k=1}^{N} \sqrt{K_k}\sigma_k\alpha_k$, and in step 3, S_{i+1} is replaced by $S_{i+1} = S_i - \sqrt{K_i}\sigma_i\alpha_i$. To reduce the complexity, one can set $C=C_i=0$ and avoid the updating and computation of this model parameter. In that case, observe that Q_i^* in step 2 is simply,

$$Q_i^* = \sqrt{\frac{AK_i}{\tilde{B}_i} \frac{\sigma_i}{\alpha_i} S_i} \; ,$$

or equivalently,

$$Q_i^* = \sqrt{\frac{A_i}{T_i}}, \quad \text{where } A_i = A\,K_i \text{ and } T_i = \frac{\alpha_i \sigma_i}{S_i} \tilde{B}_i .$$

Any subset of the different techniques described in "Alternative Implementations" can be combined and used together.

Updating Parameters of the Encoder Model.

The following is one technique for updating the parameters K_{i+1} and C_{i+1} in the quantizer controller 22. This update technique is used with the adaptive mode described above in step 4. Other classical parameter estimation or model fitting techniques such as least squares, recursive least squares, Kalman prediction, etc. can alternatively be used. The model parameters can be updated in every block, frame, group of blocks, or group of frames.

The model parameters in one embodiment of the invention, are updated or estimated on a block-by-block basis using the following weighted averages,

$$\hat{K}_i = \frac{(B_i' - A\ C_i) Q_i^{*2}}{A\sigma_i^2}, \text{ and } \hat{C}_i = \frac{B_i'}{A} - K_i \frac{\sigma_i^2}{Q_i^{*2}}.$$

The values of K and C predict B_i' using equation 2. Alternatively, in some codecs these formulas are used for measuring $\hat{K}_i$ and $\hat{C}_i$:

$$\hat{K}_i = \frac{B'_{DCT,i}\ Q_i^{*2}}{A\sigma_i^2}, \text{ and } \hat{C}_i = \frac{B_i' - B'_{DCT,i}}{A},$$

where $B'_{DCT,i}$ is the number of bits spent for the DCT coefficients of the i-th image block.

The averages of the $\hat{K}_i's$ and $\hat{C}_i's$ are computed as follows,

$$\tilde{K}_i = \frac{i-1}{i}\tilde{K}_{i-1} + \frac{1}{i}\hat{K}_i, \text{ and } \tilde{C}_i = \frac{i-1}{i}\tilde{C}_{i-1} + \frac{1}{i}\hat{C}_i .$$

The updates are a linearly weighted average of $\tilde{K}_i$, $\tilde{C}_i$ and their respective initial estimates K_1, C_1,

$$K_{i+1} = \frac{i}{N}\tilde{K}_i + \frac{N-i}{N}K_1, \text{ and } C_{i+1} = \frac{i}{N}\tilde{C}_i + \frac{N-i}{N}C_1.$$

If the general model in equation 10 is used, a variety of estimators can be used to estimate the additional parameters ϕ and γ. These parameters can also be updated on a block-by-block basis, and the ith updates ϕ_i and γ_i can be found using averaging techniques similar to those for K_i, C_i.

Selection of the α_i Weights.

The α_i values can be chosen to incorporate the importance or weight of block distortions. If default values are used $\alpha_1 = \alpha_2 = \ldots = \alpha_N = 1$, the MSE distortion is minimized between the original and the encoded blocks. Otherwise, the MSE distortion decreases in blocks with larger α_i's and increases where the α_i's are smaller. Two examples are described below for choosing the α_i weights. A region, such as a rectangular window in a video telephone image, is assigned a larger value of α_i and, in turn, smaller quantization values. The weighted region will be coded with better quality since a smaller quantization scale is used to quantize pixel values.

People usually pay more attention to the central region of a picture. Thus, larger values of α_i are assigned to the regions near the center of the picture. A pyramid formula is used to assign larger values of α_i to blocks closer to the center of the frame. Specifically, let B_X and B_Y be the number of blocks along the horizontal and vertical coordinates, respectively. The weight for the i-th block is computed as follows,

$$\alpha_i = a_1\left(1-\left|b_X - \frac{B_X}{2}\right|\frac{2}{B_X}\right)\left(1-\left|b_Y - \frac{B_Y}{2}\right|\frac{2}{B_Y}\right) + a_2,$$

where $(a_1 + a_2)$ and a_2 are the height and offset of the pyramid, respectively, and b_X and b_Y are the horizontal and vertical position of the block in the frame. For example, choosing a_1=15 and a_2=1 causes the α_i value of the center block to be 16 times that of boundary blocks.

Block Joining

In a codec, the values of the quantizer values used $Q^*_1, \ldots, Q^*_N$ (see step 2 above) need to be encoded and sent to the decoder. For example, in H.263, quantizer values are encoded in a raster-scan order and there is a five-bit penalty for changing the quantizer value. At high bit rates, the bit overhead for changing the quantizer values is negligible and the optimization techniques described above are effective. However, at very-low bit rates, this overhead is significant and some technique is needed for constraining the number of times that the quantizer changes. Unfortunately, existing optimization methods that take quantization overhead into account are mathematically inaccurate or computationally expensive.

In another aspect of the invention, a heuristic method joins blocks of similar standard deviation together into a set so that the quantizer value remains constant within the set. This technique is referred to as block joining, and reduces the changes of the quantizer at lower bit rates. Block joining is accomplished by choosing the values of the α_i weights as follows,

$$\alpha_i = \begin{cases} 2\dfrac{B}{AN}(1-\sigma_i)+\sigma_i & \dfrac{B}{AN} < 0.5 \\ 1 & \text{otherwise} \end{cases},$$

where $B/(AN)$ is the bit rate in bits per pixel for the current frame. The values of B, A, and N were defined earlier as the number of bits available, number of pixels in a block, and number of blocks, respectively. If the bit rate is above 0.5, the α_i's are all equal to 1 and hence have no effect. At lower bit rates, the α_i's linearly

approach the respective σ_l's and progressively reduce the range of the Q*'s. In fact, if the bit rate is 0, then $\alpha_l = \sigma_l$ and all the quantizer values are equal, and hence all blocks are joined into one set,

$$Q_1^* = \ldots = Q_N^* = \sqrt{\frac{AK}{(B - ANC)} \sum_{k=1}^{N} \sigma_k^2}\,.$$

FIG. 6 is a detailed block diagram of the quantizer controller 22 shown in FIG. 2. The quantizer controller 22 in one embodiment is implemented in a general purpose programmable processor. The functional blocks in FIG. 6 represent the primary operations performed by the processor. Initialization parameters in block 31 are either derived from pre-processing the current image or from parameters previously derived from previous frames or from prestored values in processor memory (not shown). Initialization parameters include N_1, S_1, B_1, K_1 and C_1 (or K_{N+1} and C_{N+1} from a previous frame).

The image is decomposed into N image blocks 14 (FIG. 2) of A pixels in block 30. The energy of the pixels in each block is computed in block 32. The weight factors assigned to each block are computed in block 34. The amount of energy left in the image is updated in block 40 and the bits left for encoding the image are updated in block 38. Parameters for the encoder model are updated in block 42 and the number of blocks remaining to be encoded are tracked in block 44. The processor in block 36 then computes the optimized quantizer step size according to the values derived in blocks 32, 34, 40, 38, 42 and 44.

Having described and illustrated the principles of the invention in a preferred embodiment thereof, it should be apparent that the invention can be modified in arrangement and detail without departing from such principles. I claim all modifications and variation coming within the spirit and scope of the following claims.